The cognitive science of holes and cast shadows

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Due to their peculiar nature of 'quasi-objects', or 'negative objects' (absences with a shape), shadows and holes are a promising source of insight about the representation of physical objects in cognition. In philosophy, informal conceptual analysis has uncovered interesting common features. (1) Both holes and cast shadows (henceforth 'shadows') are dependent features; they cannot exist without objects hosting/casting them. Both shadows and holes are in between being full-fledged material objects and regions of space: (2) they are similar enough to bounded regions of space, have a location, a shape, a size, and are as immaterial as space is, but (3) they are more object-like as they can persist over time and move[1].

To what extent are shadows and holes represented as object-like, and why?

We know more about shadows than we do about holes, although shadows are just that, holes in light; for light makes all the difference, turning shadows into valuable sources of perceptual information as they draw figures in it. *Perceptual* representations of shadows should be fit for the particular requirements of controlled and automatic visual information processing. ; *Controlled* cognitive processes use shadow shapes and locations as premises in inferences whose conclusions describe the spatial distribution of objects (shadow casters and screens), as in astronomy[2], in x-ray analysis, in electronic microscopy, in aerial geological photography. Renaissance painters laid down the foundations of the mathematical study of shadows, later subsumed under projective geometry. Early investigations of the *automatic* processing of shadows[3] capitalised on these results to yield shape- and space-from-shading/shadow algorithms for machine vision. Now, shadows do appear to be used at a very early stage in visual processing[4] to extract distance and position, and this raises an intriguing problem: they should be labelled as shadows very early on (i.e., as transitory features, dependent upon casters, as opposed to permanent and independent). However, marks bearing little resemblance to shadows suffice for vision, and tolerance of impossible, and generally geometrically incongruous shadows[5,6] indicates that the processing of shadows is not tuned to the exact norms of geometry. Much as they are informative, shadows also constitute noise as they are salient features of the visual scene (due to high luminance contrast at their boundary) and it takes very little to make them look like independent surface features – e.g. by drawing a line at their boundary (this is why line drawings of shadows do not work). Visual cognition eliminates this noise and provides only limited conscious access to shadows.
Putting it all together, the informativeness/noise aspect of shadows makes it reasonable for the visual system to extract from them useful information at a relatively early stage and then erase late access to shadows to prevent them from being mistaken for objects. This may explain why we are generally unable to detect shadow inconsistencies unless these are pointed out explicitly; an inconsistent or impossible shadow does not look like an impossible figure as no conflict ever arose in constructing its representation. Finally, tolerance of incongruent shadows sits well with the idea that shadows' representations are mainly position indicators (see fig. 1); this suggests that there exists an overarching perceptual representation genus, *position indicating mark*, of which *shadow* is a species (another species is *reflection*; very much like shadows, reflections indicate position but the conformity of their shapes goes unchecked). Illusions of impossible holes would be harder to construct than those of impossible shadows, as constraints dictated by light (uniformity of direction from a single source) do not have a counterpart in the domain of holes.

As to *conceptual* representations, shadows and holes appear to be treated as object-like in early development[7]. Infants do not find it surprising if shadows cast on an object move when the object moves; and they are conversely surprised when the movement of the object leaves the shadow in its place. It is as if shadows were patches glued to the object, thus violating condition (1) and endorsing conditions (2)-(3). There is evidence that holes too are treated like this, at least at a later developmental stage[8]; they can be categorized, tracked and counted, and in such tasks they are more advantaged than other non-objects such as parts.

The cognitive science of holes is in its infancy. It is still controversial whether topological complexity (expressed by the number of holes in an object) is taken into account by perception[9], little is known about

perceptual representations of holes (are holes construed as 'negative parts'?) and about the intuitive principles of classification of holes. Holes have a shape, but they are seen where a background region is seen and this creates a paradox, as contours are not assigned to background regions. The shape of holes may be perceived indirectly: the surrounding object is assigned a contour, which the hole inherits[10]. The ecological properties of holes (passages, openings) are likely to make their perceptual representations very different functionally from shadow representations.

Emerging research directions/questions concerning shadows, holes, and objecthood include:

-If shadows and holes are tracked by vision, then it appears that vision does not require that full-fledged objects be its main target.
-If shadows and holes are tracked as object-like in experiments using the Movable Object Target paradigm, then (a) at most two objects should be trackable in the presence of their shadows, and (b) holes could be valid distractors.
-If 'position indicating mark' is processed independently of geometric constraints, then it is possible to modify the shape of the shadow erratically without affecting the extraction of the position of a moving caster. A possible double dissociation can be hypothesized : is shape *of* shadow processed ventrally, whereas position *from* shadow is processed dorsally, disregarding the properties that could be relevant for establishing congruence?
- If cast shadows are an instance of 'position indicating mark', then psychologically cast and attached shadows are *not* two species of the same genus: the standard classification of cast, attached, and self-shadows reflects pictorial practice but may not correspond to psychological natural kinds.
-To end, a methodological question. If you are a cognitive scientist working on object perception, what in your characterization of an object rules out that shadows and holes be treated as objects – if you think they should not be considered objects?

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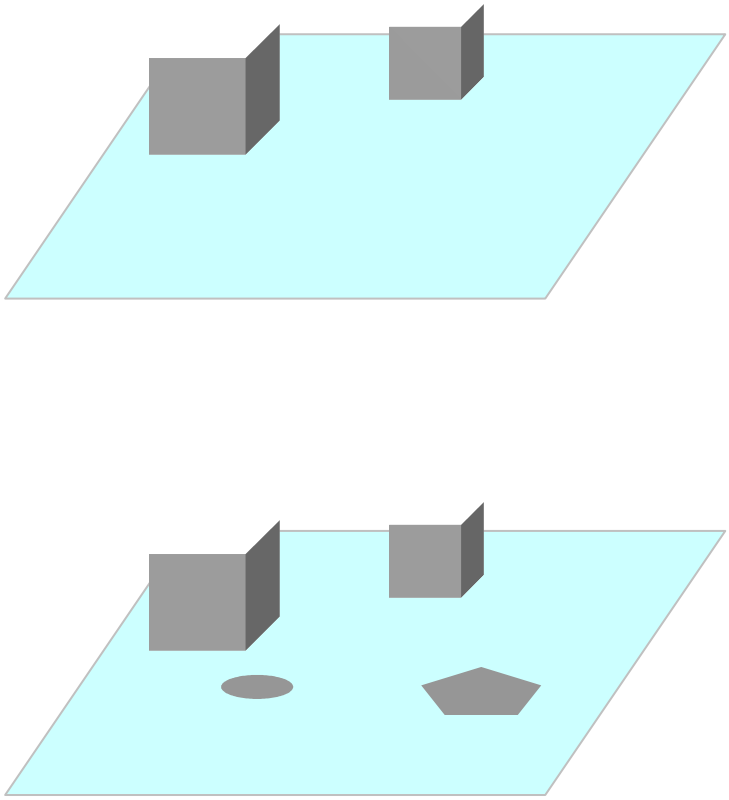

Cast shadows keep their position indicating function in spite of being incongruous to the caster. The ambiguity in the position of the two cubes (top) is resolved by adding shadows (bottom): the smaller cube is closer to the viewer and higher up relative to the surface.